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“Visual” orbit solutions from observing techniques old and new

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"Visual" Orbit Solutions from Observing Techniques Old and New

Brian D. Mason
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ABSTRACT

For the past couple of decades, the primary double star observational technique utilized at the US Naval Observatory has been speckle interferometry. Our two speckle cameras have been used on a variety of telescopes: our 26″ in Washington, the USNO (NOFS) 61″, the McDonald 82″, the Mt. Wilson 100″ and the twin 4 meter telescopes of KPNO and CTIO. While these instruments have each yielded many observations, they have been involved in rather different programs, with the 26″ observing primarily the so-called "neglected" pairs and larger instruments conducting duplicity surveys and observing close, astrophysically interesting systems.

While speckle is quite successful at resolving relatively close pairs, for those pairs which are both bright and very close long baseline optical interferometry may be the only viable solution. Utilizing both the CHARA Array and the Navy Prototype Optical Interferometer, numerous hard-to-observe pairs first resolved by speckle have been observed using these arrays' superior resolution capabilities; this has allowed these orbits to be significantly improved; examples of pairs observed by each of these instruments are presented.

At the other separation extreme, a cache of photographic plates taken with the USNO double star camera has been digitized and processed. Some 66 plates of Sirius A and B taken between 1970 and 1984, which represents a 10% increase in the total number of measures, have been reduced, enabling a significant improvement over the current "best" Sirius orbit, almost one full revolution later.

1. 26″ Speckle Observing

Due to its modest aperture, our capability to observe orbital motion pairs of astrophysical signicance is quite limited. As a result, in 2000 the program shifted over to pairs that were unconfirmed or had not been observed in a decade or more. These we defined as "neglected". The eventual goal is the characterizing of pairs as either optical or physical.

This definition was adopted by many others and has formed a productive operational observing program for us and other groups allowing the re-invigoration of observing programs with limited access to large telescopes. To date we have obtained 24,707 mean positions with our speckle camera on the 26″ telescope in Washington. As a measure of our success observing these neglected pairs (as well as others with similar programs), the number of mean positions per system in the WDS has increased from 5.8 to 7.1 despite the number of new systems ($n = 1$) increasing by 36,852 pairs.

Historically, when we obtained access to larger telescopes and observed off-base, 26″ observing would shut down for approximately a month. Due to the success of of our 26″ neglected doubles program, a second camera for use with our older ICCD was constructed in-house (Mason et al. 2007) and our primary camera has since been used when we have had access to larger telescopes, simultaneous with continued 26″ operation with our secondary camera.

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2. Large Telescope Speckle Observing

For various programs we have observed with our speckle camera on many different telescopes. These telescopes include the Naval Observatory Flagstaff Station (NOFS) 61″ telescope (neglected pairs, see Hartkopf & Mason 2008), the McDonald Observatory 82″ telescope (Hipparcos doubles, see Mason et al. 2001), the Mt. Wilson Observatory 100″ telescope (neglected pairs, see Hartkopf & Mason 2009), and the 4m telescopes of Kitt Peak National Observatory and Cerro Tololo Interamerican Observatory (massive stars, see Mason et al. 2009). Other data are in process.

These programs include astrophysically interesting orbit pairs, surveys for new companions, fainter and southern hemisphere pairs. These programs have resulted in 3608 observations, 89 new pairs, and 260 orbits. Additional observations have also been obtained with the SOAR 4.2m telescope with HRCam (Tokovinin et al. 2010).

An example of an individual system of interest over a long period of time was given the memorable moniker "Tweedledum and Tweedledee". This pair of nearly identical interferometric pairs was discovered by Finsen (FIN 332, 1953). The similarity in brightness, separation and orientation led to many issues of misidentification as well as orbital quadrant ambiguities. It has been under regular observation by speckle inteferometry since the 1970s, most notably by CHARA and USNO. Older unpublished CHARA observations and USNO speckle observations from all the above large telescopes were included in an analysis of both pairs resolving the long-standing quadrant issues (Mason et al. 2010a). Investigation also indicates they are within 1σ of being co-planar.

Additional orbits of southern interferometric pairs have also been presented (Figure 1; Mason et al. 2010b) and others are in preparation. For these figures, the dashed curve is the previous best orbit. The filled stars are USNO observations published since the time of the dashed curve, filled circles are other observations since then, and the solid curve is the new orbit based on all data.

3. Navy Prototype Optical Interferometer

The Navy Prototype Optical Interferometer (NPOI) is located on Anderson Mesa, outside Flagstaff, Arizona. See Zavala et al. (2010) for an example of NPOI double star work. The current operational baseline allows routine observing to a resolution of 1 mas. Ultimately this capability will be $\sim$200 μas. This R to V band instrument has a current limit of V $\sim$6. This will be extended significantly when the former Keck Interferometer outrigger 1.8m telescopes are integrated.

Mason et al. (1997) published combined solution orbits of three hot dwarf & cool giant pairs: HR 233, 36 Tau and 73 Leo. While the single lined RV spectroscopy and deconvolved composite spectra are quite good, the resolved measures were hampered by the inability to resolve the pair at all orbital phases, even with speckle interferometry on the largest accessible telescopes. While long baseline optical interferometry solves this problem, the magnitude difference (Δm) in the infrared, where interferometers work best, generates other problems. The V band operation of the NPOI makes it ideal for these targets. See Figure 2.

Other hot dwarf & cool giant pairs are also under investigation. One of the longest period eclipsing systems, γ Per, is very well characterized in one quadrant, but has no observations in the other. From 2019.7 to 2021.1 this pair is expected to be at less than 30 mas separation and will spend part of that time in the opposite quadrant. Coverage here will characterize the orbit quite well. Another rarely resolved challenging system is τ Per (McAlister 1981). This cool giant & hot dwarf pair is ideal for the capabilities

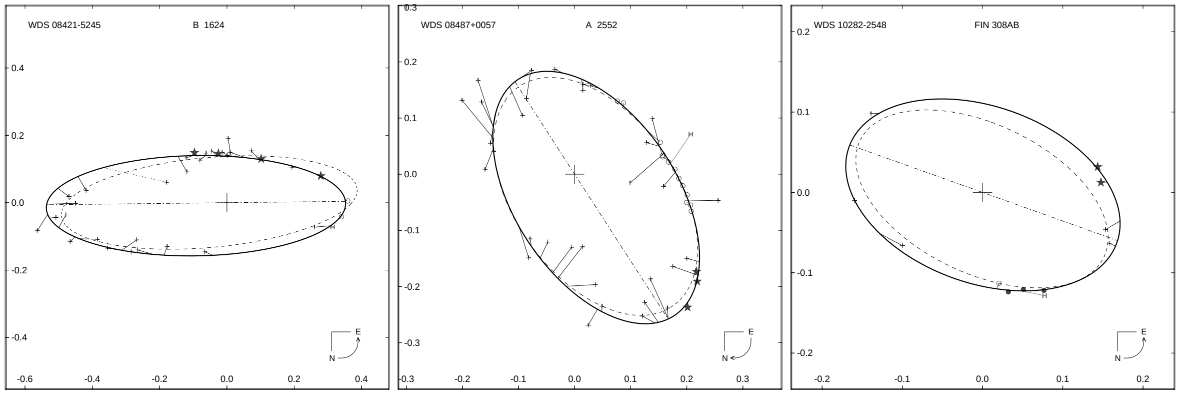

Fig. 1.— New orbital solutions, plotted together with all published data in the WDS database. In each of these figures, micrometric observations are indicated by plus signs, modern interferometric measures by filled circles, and older eyepiece interferometry measures by open circles; Hipparcos measures are indicated by the letter 'H'. The new measures enabling these orbital improvements are indicated as filled stars. "$O-C$" lines connect each measure to its predicted position along the new orbit (shown as a thick solid line). Dashed "$O-C$" lines indicate measures given zero weight in the final solution. A dot-dash line indicates the line of nodes, and a curved arrow in the lower right corner of each figure indicates the direction of orbital motion. Finally, the previous published orbit is shown as a dashed ellipse. These orbits are from (left to right) Mason et al. (1999), Hartkopf & Mason (2000) and Docobo (1991).

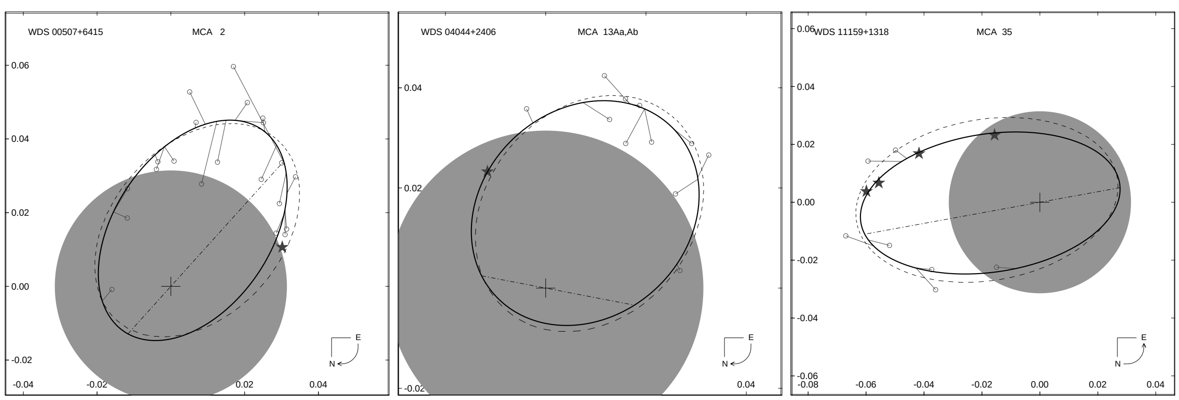

Fig. 2.— New orbital solutions, plotted together with all published data in the WDS database as well as unpublished NPOI observations. In each of these figures, modern interferometric measures are plotted as open circles and the filled stars indicate the NPOI measures. The large shaded circle centered on the origin is the 30 mas V band resolution limit of speckle interferometry on a 4m telescope. The previous orbits (dashed curves) are from Mason et al. (1997). Other symbols are as in Figure 1. Observation of these pairs are ongoing. New orbits are courtesy of USNO summer intern Haley Hurowitz.

of the NPOI. In the case of δ Sge the pair is a hot dwarf and a cool supergiant. The orbit of Eaton et al. (1995) had no reliable observations due west at the closest separations. Successful NPOI observations of all these pairs have been obtained, and observations continue.

4. CHARA Array

The CHARA Array, on Mt. Wilson in California, is an interferometer similar in configuration to the NPOI. The emphasis on achieving results on the longest baselines in infrared makes this instrument capable of higher resolution than the NPOI at present. However, most results are pairwise and give the interferometer observables of baseline and visibility. Combining multiple baseline pairs allows triangulation of the binary through analysis of their separated fringe packets (SFP). This methodology is thoroughly explored in Farrington et al. (2010).

While HD 178911 is observable for much of its orbit with single aperture interferometry, the improved accuracy and precision of SFP observations, plus the capability to resolve at less than 30 mas, have made this pair very attractive. Publication of the SFP solution is expected following the 2011 observing season. The pair μ Ari has a SFP measure in the hitherto unresolved region due south and to the west. The 2011 observable wedge here is due north in a region not well covered before. See Figure 3.

A recent application of multiple systems is to use the wider single component in a multiple system as the calibrator of the close binary. In this case, the wider pair is a known speckle binary appropriate for speckle interferometry and SFP solutions. An orbital analysis of both systems from speckle interferometry, SFP work, baseline/visibilty interferometry data as well as spectroscopy has recently been presented (ten Brummelaar et al. 2011). This orbit is also plotted in Figure 3.

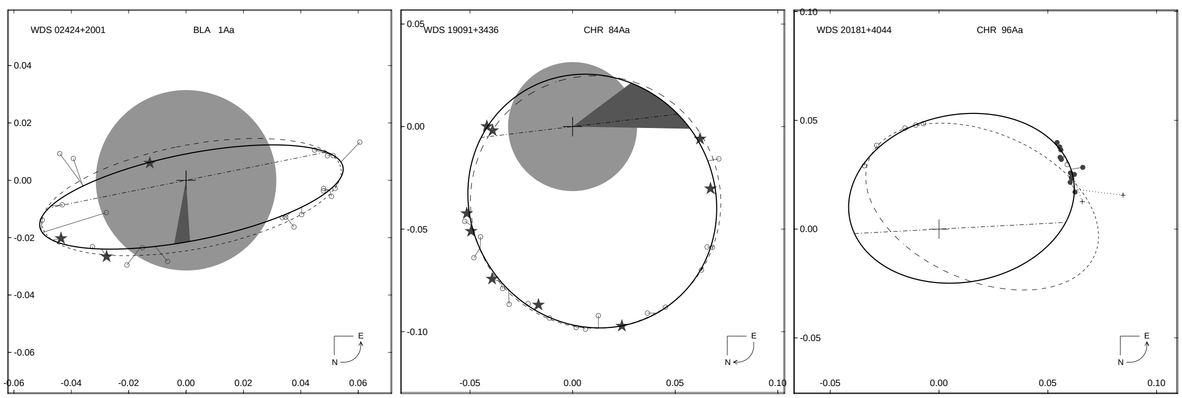

Fig. 3.— New orbital solutions, plotted together with all published data in the WDS database as well as unpublished CHARA observations. In each of these figures, published interferometric measures are plotted as open circles and filled symbols indicate the CHARA SFP measures. The large shaded circle centered on the origin is the 30 mas V band resolution limit of speckle interferometry on a 4m telescope. The previous orbits, indicated as a dashed curve, are from (left to right) Mason (1997), Hartkopf et al. (2000) and Hartkopf et al. (1993). For the left and center figures, the shaded wedge indicates where the companion is expected to be in Fall 2011 when the pairs are scheduled for observation. Here filled stars indicate CHARA SFP measures obtained over the last several years which are unpublished. For the pair at right, the published SFP measures are plotted as filled circles. The orbit is the new speckle+SFP+RV determination of ten Brummelaar et al. (2011). Other symbols are as Figure 1.

5. Photographic Data: Sirius

At the other separation extreme, a cache of photographic plates taken with the USNO double star camera has been digitized and processed, using the method described by Lindenblad (1970). Some 66 plates of Sirius A and B taken between 1970 and 1984, which represents a 10% increase in the total number of measures, have been reduced. They enable a significant improvement over the current "best" Sirius orbit (van den Bos 1960), almost one full revolution later. The orbit is presented in Figure 4.

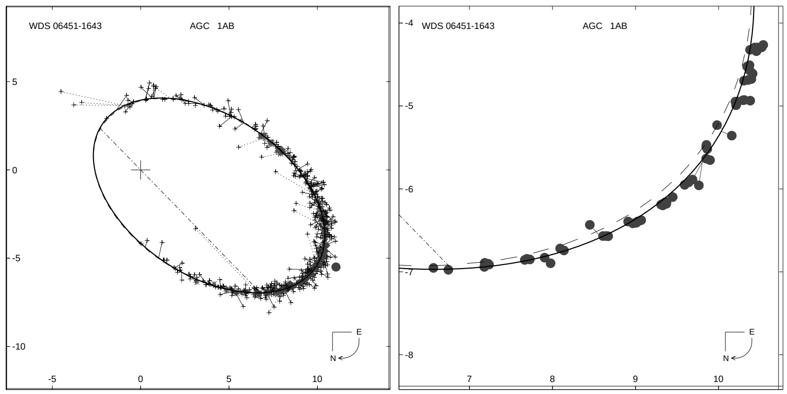

Fig. 4.— New orbital solutions for Sirius. In the figure at left all published data in the WDS database as well as unpublished USNO photographic observations (filled circles) are plotted. In the figure at right a 4× zoom of the lower right plots only the newly reduced observations, the new orbit as a solid curve and the current "best" orbit (van den Bos 1960) as a dashed curve. New orbit are courtesy of USNO summer intern Miranda Seitz-McLeese. Final calibration of these data is being performed with the assistance of USNO retiree Jerry Josties.

Currently, the technique utilized most frequently for systems with large magnitude difference is adaptive optics. We are also exploring continued work in this area (Turner et al. 2008).

6. Conclusions

While we continue to utilize speckle interferometry as our primary observational technique, the parameters of separation, magnitude and differential magnitude require a plethora of methods each of which covers different portions of $\rho - m - \Delta m$ space. We will continue to seek out partnerships with other groups to address them.

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